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Development of Scientific Competencies in Future Biology Teachers Through Field Practice: The Case of Tian Shan Mountain Ash (*Sorbus Tianschanica*)

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ABSTRACT
This study investigates how educational field practice can foster research competencies in future biology teachers, using the Tian Shan mountain ash (Sorbus tianschanica Rupr.) as a regionally significant object of inquiry. A quasi-experimental design was implemented during one academic semester (2024–2025) with second-year undergraduates enrolled in the 6B01508 Biology program: a control group (n = 21) and an experimental group (n = 31). Both groups followed the same curriculum, while the experimental group engaged in a research-based instructional approach that integrated field sampling, cytohistological preparation, microscopy, quantitative biometry, and the interpretation of rooting experiments. Plant material consisted of annual shoots collected from maternal plants of different ages in the Zhetysu Alatau; cytohistological analyses were conducted in the Laboratory of Bioresources of the Research Institute of Biotechnology and Ecology at Zhetysu State University named after I. Zhansugurov. Biological results indicated a diffuse-porous wood structure with predominance of uniseriate rays, supporting a moderate rooting potential that increased significantly under growth regulators (ANOVA: $p < .001$; Kruskal–Wallis: $p < .001$). Pedagogical assessment employed a three-component model (motivational, cognitive-content, and activity-based) across three measurement stages. At the final assessment, the distribution of research competence levels differed significantly between groups ($\chi^2 = 16.16$, df = 2, $p < .001$) with a large effect size (Cramér's V = .56); no students in the experimental group remained at the low competence level. The findings suggest that integrating authentic anatomical and histological research on endemic flora into undergraduate biology teacher education can strengthen students' motivation, conceptual understanding, and independence in scientific inquiry, providing a scalable model for practice-oriented curriculum design.

KEYWORDS
Research competencies; biology teacher education; field-based learning; Sorbus tianschanica Rupr; anatomical structure; adventitious root formation.

INTRODUCTION

In contemporary education, competencies are understood not only as a body of knowledge but also as the ability to apply it effectively in professional practice. In the training of future biology teachers, research competencies are especially important, as they encompass scientific analysis, critical thinking, hypothesis formulation, experimentation, and interpretation of results. These competencies contribute to professional development, support innovative teaching practices, and enable teachers to organize research-oriented learning.

In contemporary higher education, the concept of competence extends beyond the acquisition of disciplinary knowledge to encompass the ability to apply it in professional and research-oriented contexts. Within biology teacher education, research competence is regarded as a key outcome, integrating cognitive, motivational, and activity-based components that enable future teachers to engage in scientific inquiry, interpret empirical data, and design research-informed learning environments (Bespalko, 1989). Beyond cognitive and activity-based components, contemporary research highlights that the professional development of future educators also benefits from incorporating sociocultural perspectives (Martín-Gutiérrez & Sevillano-Monje, 2025).

The theoretical foundations of research competence development are rooted in constructivist and experiential learning theories. Dewey's concept of learning through experience emphasizes the role of direct interaction with real-world phenomena in the formation of reflective and critical thinking (Dewey, 1910). Vygotsky's sociocultural theory further highlights the importance of guided activity and social interaction in the development of higher mental functions, including research skills (Vygotsky, 1934). These ideas were later expanded within critical pedagogy, where Freire (1970) emphasized learner agency, inquiry, and problem-posing as central to meaningful education.

In recent decades, competence-based and inquiry-oriented approaches have become dominant frameworks in science teacher education. International research demonstrates that inquiry-based learning and research-integrated instruction significantly enhance preservice teachers' analytical thinking, methodological literacy, and readiness for independent research (Koberstein-Schwarz et al., 2024; Manganyi, 2025; Owens et al., 2021). Systematic reviews indicate that research competence develops most effectively when students are actively involved in authentic scientific practices rather than simulated or purely classroom-based tasks (Magaji et al., 2024; Matjašič, 2024; Naudé & Pretorius, 2024; Pretorius et al., 2023).

Field-based learning occupies a special place within inquiry-oriented biology education. Numerous studies confirm that outdoor and field practices provide unique opportunities to observe natural variability, formulate research questions, and apply theoretical knowledge in situ (Kervinen et al., 2020; Mann et al., 2022). Fieldwork has been shown to positively affect students' motivation, conceptual understanding, and long-term engagement with scientific inquiry (Entress, 2023; Hu et al., 2025). Moreover, comparative studies reveal that real field experiences are more effective in developing place-based understanding and research skills than virtual or simulated alternatives (Zhao et al., 2020).

Within teacher education, field practice is increasingly viewed not only as a means of professional familiarization but also as a core component of the formation of research competence. Empirical studies across diverse educational contexts show that participation in field research significantly improves preservice teachers' ability to design experiments, collect and analyze data, and reflect on methodological limitations (Hujjatusnaini et al., 2022; Irwanto et al., 2023). In the context of biology education, botanical field practice is particularly valuable due to its integrative nature, combining anatomy, morphology, ecology, and systematics (Anisimova et al., 2020).

Recent literature also emphasizes the importance of using regionally significant and endemic species as objects of educational research. Integrating local biodiversity into university curricula not only enriches subject knowledge but also fosters environmental responsibility and contextualized scientific thinking (Hu et al., 2025; Ramírez-Castañeda et al., 2022; Sirih et al., 2025). Studies focusing on conservation-oriented education highlight that working with endemic plant species strengthens students' motivation and awareness of applied biological research (Barnogul & Khilola, 2022).

Assessment of research competence remains a methodological challenge in teacher education. Contemporary approaches propose multidimensional models that include motivational, cognitive, and activity-based indicators (Aydin et al., 2024; Putnam et al., 2021). Validated instruments, such as the ERLA and similar research skills scales, provide evidence that competence development can be reliably measured through a combination of self-assessment, performance tasks, and expert evaluation (Butz et al., 2020; Daryanes et al., 2025). Recent studies also stress the importance of reporting effect sizes alongside significance testing to ensure the transparency and validity of pedagogical experiments (Protasova, 2020).

In the context of Kazakhstan, research on competence-based biology education highlights the growing role of experimental and field-based learning in preparing future teachers for modern educational challenges (Mukasheva et al., 2019; Taubayeva & Kudaibergeneva, 2022). However, despite positive trends, there remains a need for empirically grounded models that integrate biological research with systematic pedagogical assessment. This gap underscores the relevance of studies that combine anatomical and morphological plant research with structured evaluation of research competence development.

Thus, existing literature confirms that field-based, inquiry-oriented learning grounded in authentic scientific practice is a powerful means of developing research competence in future biology teachers (Acheampong et al., 2024; Chura-Quispe et al., 2024; dos Santos et al., 2022). At the same time, there is limited research that addresses biological experimentation, regional biodiversity, and pedagogical measurement simultaneously. The present study seeks to contribute to this field by integrating anatomical and histological research on *Sorbus* *tianschanica* Rupr. into undergraduate biology education and by empirically assessing its impact on the formation of research competencies.

Botanical characteristics of the Tian Shan mountain ash

Sorbus tianschanica Rupr. is a deciduous tree or large shrub of the family Rosaceae, native to the mountain systems of the Tian Shan and Jetisu Alatau at altitudes of 1300–3600 m above sea level. It belongs to the division Magnoliophyta, class Magnoliopsida, and genus *Sorbus*. In Kazakhstan, three species of *Sorbus* are represented, including *S. tianschanica*, which is characterized by pinnate leaves, white corymbose inflorescences, and red berries ripening in late summer. The species plays an important ecological role as a food source for wildlife.

Objective and tasks of the study

The objective of the study is to develop research competencies in students of the 6B01508 "Biology" program through field-based learning. The study aims to analyze the anatomical structure of annual shoots of *Sorbus tianschanica* Rupr. (Fig. 1) on transverse and longitudinal sections, predict root-forming ability based on ray parenchyma structure, assess rooting of green and lignified cuttings using growth regulators, and evaluate the development of students' research competencies through pedagogical measurements.

Figure 1.

Tian Shan mountain ash

(Source: compiled by the authors)

Research Questions and Hypotheses

The following questions guided the study:

1. Does field-based research-integrated curriculum focusing on *S. tianschanica* lead to a significant increase in the research competence of pre-service biology teachers compared to a traditional curriculum?
2. To what extent do the motivational, cognitive-content, and activity-based components of research competence change in response to the intervention?

We hypothesized that the experimental group would show significantly greater gains across all three components from pre-test to post-test, and that a larger effect size would emerge in the activity-based component due to the hands-on nature of the tasks.

MATERIALS AND METHODS

Study Design

A quasi-experimental pretest/posttest control-group design was employed. The pedagogical intervention was embedded in the regular 2024–2025 academic semester curriculum of the 6B01508 Biology undergraduate program at I. Zhansugurov University. Two intact groups were used: a control group (n = 21) and an experimental group (n = 31). Groups were pre-existing course sections (non-randomized). The pre-intervention measurement of research competence confirmed initial comparability. All students attended the same compulsory courses (*Plant Anatomy and Morphology*, *Plant Systematics*, *Genetics*, *Plant Physiology*). The experimental group additionally engaged in a series of research-based field and laboratory tasks focused on *Sorbus tianschanica* Rupr.

Participants

Second-year undergraduate students (mean age 19.2 ± .8 years) enrolled in the biology teacher education program. The control group comprised 21 students (18 female, 3 male), the experimental group 31 students (26 female, 5 male). No statistically significant differences in prior academic achievement (GPA) or initial research competence level were detected. All participants provided informed consent for the anonymous use of their assessment data.

Research Competence Framework and Instruments

Research competence was operationalized through a three-component model (motivational, cognitive-content, and activity-based components) derived from Bespalko's (1989) pedagogical technology framework. For each component, a set of indicators was defined. Assessment instruments included:

- *Motivational component*: a researcher-designed Likert-type questionnaire (15 items, α = .84) on interest, value orientation, and willingness to engage in research; systematic observation protocols.
- *Cognitive-content component*: a 25-item test on anatomy, morphology, and histology of woody plants; coefficient of knowledge acquisition completeness (based on Bespalko, 1989).
- *Activity-based component*: a standardized performance assessment rubric (3 criteria: independence in planning, methodological accuracy, data interpretation) scored on a 0–10 scale; inter-rater reliability between two independent assessors was κ = .78 (Cohen's kappa). Assessors were blind to student group membership.

Intervention Procedure

The field-based research intervention consisted of five sequential stages integrated into the laboratory and field components of the above courses:

1. Field sampling of annual shoots of *S. tianschanica* in the Zhetysu Alatau (Zhungar Alatau State National Natural Park).
2. Cytohistological preparation in the Laboratory of Bioresources: fixation, sectioning (transverse, tangential, radial), staining, and microscopic examination.
3. Quantitative biometry of ray parenchyma (cell type classification, ray order, dimensions) and tissue proportion analysis.
4. Experimental rooting of green and hardwood cuttings treated with IAA and IBA at five concentrations (10, 25, 50, 75, 100 mg/L) and controls.
5. Interpretation of anatomical data to predict rooting potential and comparison of experimental rooting outcomes with structural predictions.

Each stage was completed during scheduled laboratory sessions and a three-day field trip. Students worked in small teams (3–4 members) under the instructor's guidance, gradually progressing from structured protocols to independent mini-investigations.

Data Collection and Analysis

Biological data: Tissue proportions, ray cell dimensions, and rooting percentages were recorded in 3–5 replications. Inferential statistics (one-way ANOVA with Tukey's HSD post-hoc test or Kruskal–Wallis test when normality was violated) were used to compare rooting percentages across concentrations and treatment types. Normality was assessed using the Shapiro–Wilk test, and homogeneity of variances was assessed using Levene's test. Effect sizes (η^2) were reported for significant ANOVA results.

Pedagogical data: Three measurements (pre-test, mid-test, post-test) of research competence were conducted. Between-group differences at each stage were tested with Pearson's chi-square test (for categorical competence levels: low, medium, high) or Fisher's exact test when expected frequencies were < 5. Effect size was estimated with Cramér's *V*. Descriptive statistics and mean competence indices were also calculated. All analyses were performed in SPSS 26.0; significance level was set at $\alpha = .05$.

Curriculum Alignment

To address the journal's focus, we mapped the intervention onto Tyler's four curriculum dimensions:

- *Objectives*: Development of research competencies (motivational, cognitive, activity-based) through inquiry-based fieldwork.
- *Materials*: Original micrographs, biometric datasets, live *S. tianschanica* specimens, and laboratory protocols.
- *Method*: Research-integrated teaching combining direct field experience, microscopy, and independent data interpretation.
- *Assessment*: Three-component competence assessment with validated instruments, inter-rater reliability checks, and effect-size reporting.

Plant material and cytohistological procedures

The study focused on the ray parenchyma of the Tian Shan mountain ash (*Sorbus tianschanica* Rupr.; Magnoliophyta, Magnoliopsida, Rosaceae, *Sorbus*). Plant material was collected in the Zhungar Alatau State National Natural Park (Republic of Kazakhstan) (Fig. 2). Annual shoots were sampled in summer and during the autumn–winter–spring period after leaf fall from donor plants of different ages used for green cutting propagation (Bakhtaulova et al., 2021). Shoots were taken from the middle crown zone with different exposures (N, S, E, W).

Figure 2.

Collection sites of Tian Shan mountain ash cuttings in Zhetysu Alatau

(Source: compiled by the authors using Google Maps)

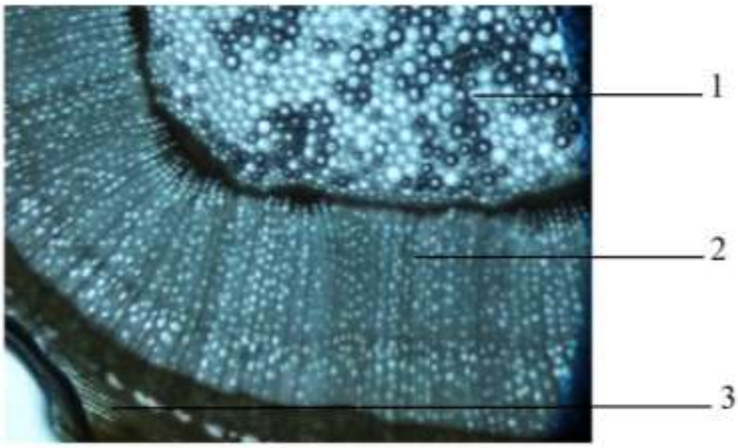
Cytohistological analyses were performed in the Laboratory of Bioresources at Zhetysu State University named after I. Zhansugurov.

The lower third of annual shoots was fixed in 70% ethanol with glycerin (1:4, v/v). Because adventitious roots may initiate in nodes and internodes and nodal anatomy is more complex, analyses were restricted to internodes. Transverse and longitudinal (tangential and radial) sections (25–50 µm) were prepared using a manual microtome, stained with aqueous blue and chrysoidin, mounted in glycerin, and examined under an MBI-3 binocular microscope (8×, 20×, 40× objectives; 7× and 15× eyepieces). Approximately 100 sections were screened; ~20 were examined in detail (Fig. 3).

Ray order and dimensions, and ray cell dimensions were measured using an ocular micrometer (MOV-1-16) following A.A. Yatsenko-Khmelevsky. Ray order was determined near the cambial zone. Cell types were classified by axis ratio in sections: square (.85–1.25), erect (vertical axis >1.25× horizontal axis), and procumbent (horizontal axis >1.25× vertical axis). Measurements were performed in 3–5 replications with 5–20 measurements per parameter; standard biometric methods were used for data processing. Green and hardwood cuttings were collected from healthy, well-illuminated shoots (8–12 cm, 2–3 internodes). Cuttings were treated with IAA (heteroauxin) or IBA (Kornevin) at 10, 25, 50, 75, and 100 mg/L for 16 h at +18 to +22 °C. Cuttings were planted 5 cm apart at a depth of 1.5–2.0 cm and maintained under polyethylene film at +20 to +26 °C and 80–90% humidity; distilled water served as the control. Hardwood cuttings collected in autumn/spring were rooted under the same conditions. A subset required stratification: storage at −17 °C for 4 weeks, after which treatments and planting were repeated.

Figure 3.

Cross-sectional anatomical slice of an annual shoot of Sorbus tianschanica (x 100). (1 – pith; 2 – uniseriate conducting vessels of the xylem; 3 – bark)



(Source: compiled by the authors)

RESULTS

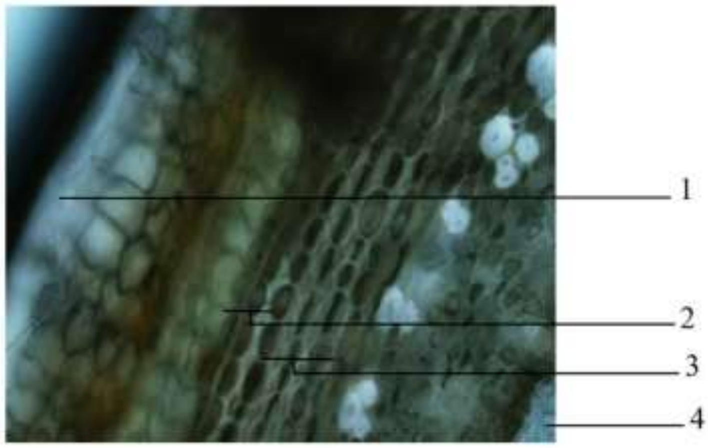
The presentation of results is organized around the two research questions that guided the study: (1) the overall effect of the field-based, research-integrated curriculum on pre-service biology teachers' research competence, and (2) the extent of change in each of the three competence components. Biological findings are reported first because they constitute the authentic scientific content that served as the vehicle for the pedagogical intervention, thereby directly supporting the answer to the first research question.

Biological Results: Anatomical Structure and Rooting Potential (content basis for the intervention addressing Research Question 1)

Cross-sections of annual shoots of S. tianschanica revealed diffuse-porous wood with a distinct pith (Figure 3). Tissue proportions indicated xylem comprised 46.2% of the stem radius, pith 25.7%, and bark 28.1%. Primary medullary rays were predominantly uniseriate (89.1% in cross-section; 78.6% in tangential section), with multi-row rays (2–4 rows) accounting for 10.9% and 21.4%, respectively (Figure 4). Ray parenchyma cells in the perimedullary zone were initially square-to-erect, shifting to procumbent with cambial growth. Mean ray height was 150–180 µm (uniseriate) and 120–150 µm (2–3-row rays). The moderate proportion of procumbent cells suggested a rooting potential >30% under favourable conditions.

Figure 4.

Tangential parenchyma of Tian Shan mountain ash wood on a tangential anatomical section (x 400)



(Source: compiled by the authors)

Table 1.

Rooting percentage of green cuttings of Tian Shan mountain ash under different concentrations of growth stimulants (%)

Growth stimulants / Concentration	10 mg/L	25 mg/L	50 mg/L	75 mg/L	100 mg/L	The average value
IAA	55±1,3	28±1,1	30±0,9	35±1,7	0	30
IBA	20±0,9	0	29±1,2	38±1,3	35±1,5	25
Control samples	16,4±0,5					

(Source: compiled by the authors)

Table 2.

Rooting Percentage of Hardwood Cuttings of Tian Shan mountain ash (Sorbus tianschanica Rupr.) Treated with Various Concentrations of Growth Regulators (%)

Growth stimulants / Concentration	10 mg/L	25 mg/L	50 mg/L	75 mg/L	100 mg/L	The average value
IAA	45±1.1	22±0.9	20±0.8	30±1.5	0	23
IBA	15±0.8	0	25±1.0	30±1.2	30±1.4	20
Control samples	9.4±0.5					

(Source: compiled by the authors)

Rooting experiments confirmed this prediction (Tables 1 and 2). For green cuttings, IAA and IBA treatments significantly increased rooting compared to controls (16.4%), with optimal concentrations of 75 mg/L IAA (35%) and 10 mg/L IBA (20%). However, IBA at 100 mg/L also yielded 35% (one-way ANOVA: $F(5, 24) = 12.14$, $p < .001$, $\eta^2 = .72$). For hardwood cuttings, rooting occurred only after stratification; the highest rate was obtained with IAA 75 mg/L (30%) and IBA 10 mg/L (40%), significantly exceeding the control (9.4%) (Kruskal–Wallis $H = 22.03$, df = 5, $p < .001$). Detailed values for each concentration are given in Tables 1 and 2.

Pedagogical Results: Overall Competence Development (Research Question 1) and Component-Specific Changes (Research Question 2)

The initial diagnostic measurement (pre-test) showed no significant difference between the control and experimental groups in the distribution of research competence levels ($\chi^2 = 0.84$, df = 2, p = .66, Cramér's V = .10) (Table 6, Figure 5). After the intervention, the experimental group exhibited a consistent positive shift across all three-components, allowing a direct answer to Research Question 1: the field-based, research-integrated curriculum did lead to a statistically and practically significant increase in overall research competence relative to the traditional curriculum.

Table 6.

Indicators of the formation of research competence of biology students based on anatomical, morphological, and histological analysis of Sorbus tianschanica Rupr. (First control image)

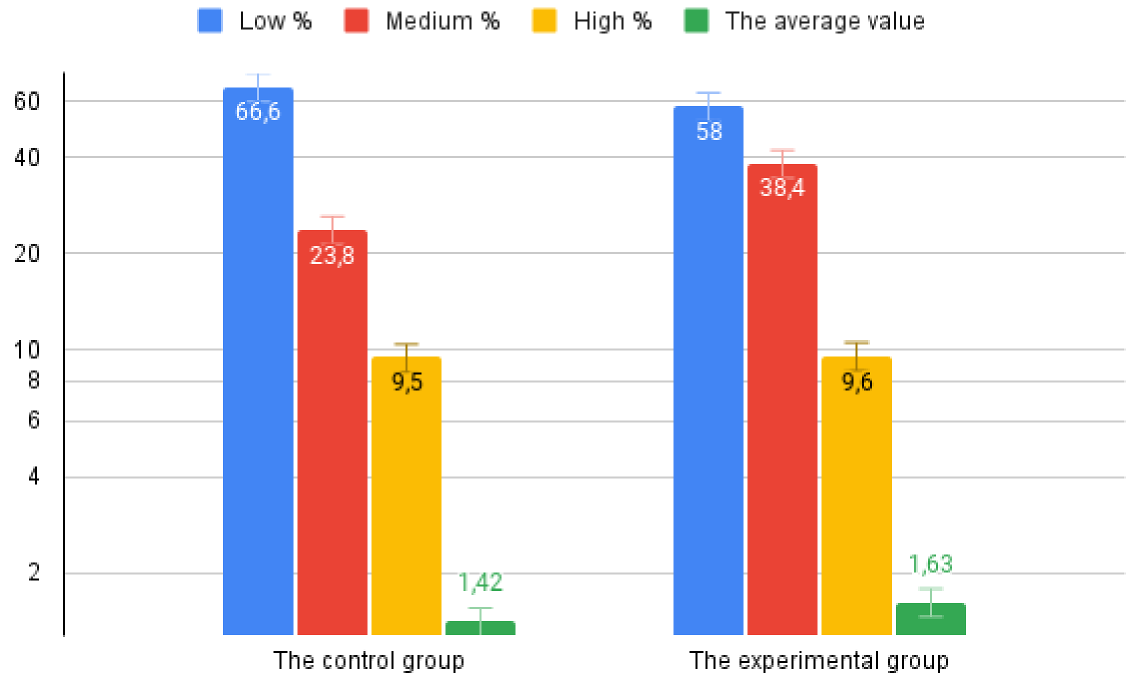
Groups	Number of students	Indicators						The average value
		Low		Medium		High		
		Number of students	%	Number of students	%	Number of students	%	
The control group	21	14	66.6	5	23.8	2	9.5	1.42
The experimental group	31	18	58	12	38.4	3	9.6	1.63

Source: Compiled by the authors.

Overall competence index (Research Question 1). The composite research competence index at post-test differed significantly between groups ($\chi^2 = 16.16$, df = 2, p < .001, Cramér's V = .56) (Figure 9). No expected cell frequencies were below 5 at this stage; for earlier stages where low counts occurred, Fisher's exact test confirmed the same pattern. The effect size is classified as large, confirming a strong association between the intervention and competence growth. Notably, no students in the experimental group remained at the low competence level.

Figure 5.

Comparison of the level of formed scientific competence among biology students.



Source: Compiled by the authors.

Changes in the three competence components (Research Question 2).

Motivational component. The proportion of students with a high motivational level increased from 2.5% to 20.5% in the experimental group, while the low-level share decreased from 48.4% to 26.3% (Table 3). The control group showed smaller gains (high: 8.7% to 19.4%; low: 55.1% to 46.5%).

Table 3.

Dynamics of changes in the motivational component of the formation of research competence among biology students based on the anatomical, morphological, and histological analysis of Sorbus tianschanica Rupr. (%)

The level of improvement of the motivational component	Before the experiment		After the experiment	
	Control group	Experimental group	Control group	Experimental group
Low	55.1	48.4	46.5	26.3
Average	38.2	49.1	34.1	53.2
High	8.7	2.5	19.4	20.5

Source: Compiled by the authors.

Cognitive-content component. The high-level proportion rose from 5.3% to 20.3% in the experimental group, compared to 4.5% to 10.4% in the control group (Table 4). The average coefficient of knowledge completeness reached 0.72 ± 0.11 vs. 0.63 ± 0.14 in the control (independent-samples t-test = 3.41, p = .001, Cohen's d = 0.71).

Table 4.

Dynamics of changes in the content component of the formation of research competence of biology students based on anatomical, morphological, and histological analysis of Sorbus tianschanica Rupr.

The level of improvement of the cognitive-content component	Before the experiment		After the experiment	
	Control group	Experimental group	Control group	Experimental group
Low	56.1	49.4	19.5	11.2
Average	39.4	45.3	70.1	68.5
High	4.5	5.3	10.4	20.3

Source: Compiled by the authors.

Activity-based component. The most pronounced change occurred here. In the experimental group, the low-level proportion dropped from 61.4% pre-test to 0% at post-test (Table 5), while the high-level share increased from 4.4% to 38.8%. The control group showed a reduction of low-level from 62.2% to 38.5% and an increase in high-level from 4.7% to 9.2%. This aligns with the hypothesis that the largest effect would emerge in the activity-based component because of the hands-on nature of the tasks.

The overall research competence index (a composite of the three-components) at post-test differed significantly between groups (χ^2 = 16.16, df = 2, p < .001, Cramér's V = .56) (Table 6, Figure 6). No expected cell frequencies were below 5 at this stage; in earlier stages with low counts, Fisher's exact test confirmed the same pattern. The effect size is classified as large, confirming a strong association between the intervention and competence growth.

Table 5.

Dynamics of changes in the activity component of research competence among biology students based on the anatomical, morphological, and histological analysis of Sorbus tianschanica Rupr.

The level of improvement of the activity-based component	Before the experiment		After the experiment	
	Control group	Experimental group	Control group	Experimental group
Low	62.2	61.4	38.5	0
Average	33.1	34.2	52.3	61.2
High	4.7	4.4	9.2	38.8

Source: Compiled by the authors.

Table 7.

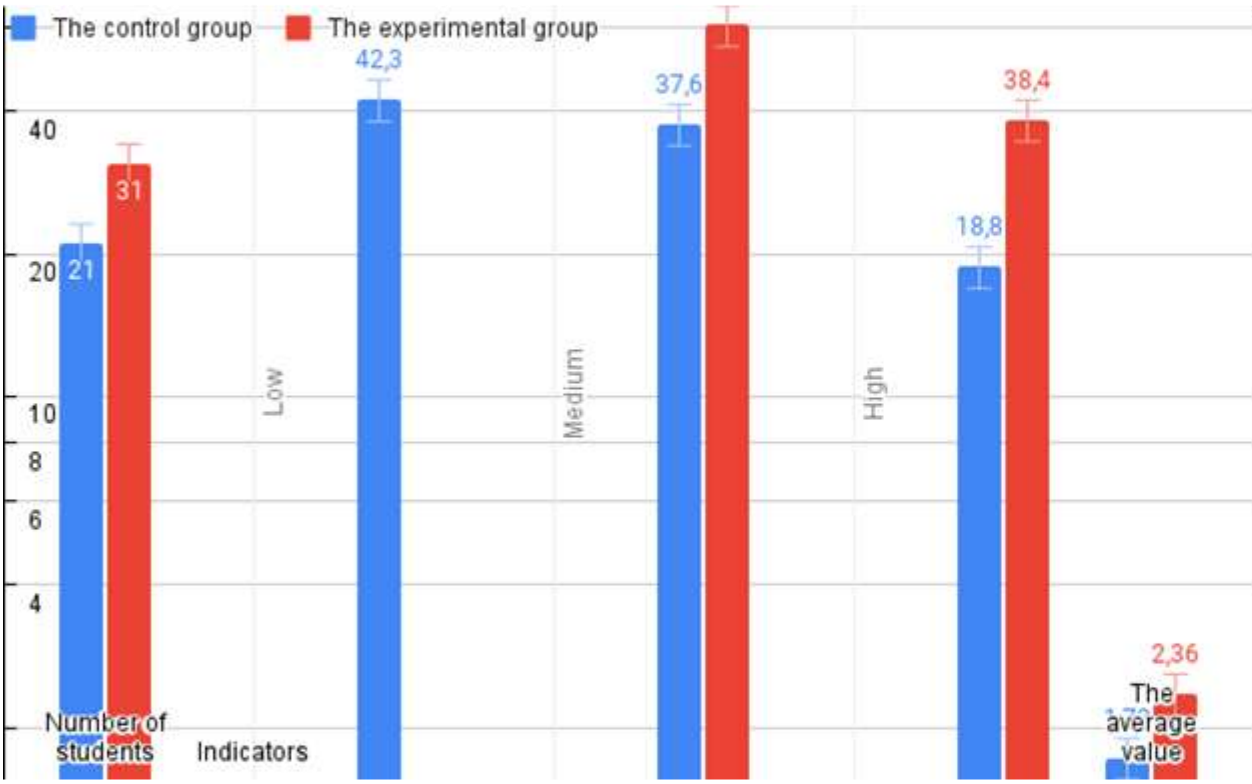
Dynamics of the development of the index of formed research competence among biology students based on the anatomical, morphological, and histological analysis of Sorbus tianschanica Rupr. (Third control measurement)

Groups	Number of students	Indicators						The average value
		Low		Medium		High		
		Number of students	%	Number of students	%	Number of students	%	
The control group	21	9	42.3	8	37.6	4	18.8	1.73
The experimental group	31	0	0	19	60.8	12	38.4	2.36

Source: Compiled by the authors

Figure 6.

Comparison of the final indicators of the level of formed scientific competence among biology students.



Source: Compiled by the authors

DISCUSSION

The present study tested a field-based pedagogical model that used the endemic plant species *Sorbus tianschanica* as a vehicle for developing research competencies in pre-service biology teachers. The findings confirm that integrating authentic anatomical research into a teacher-education curriculum can significantly enhance motivation, conceptual understanding, and independent inquiry skills. The large effect size (Cramér's V = .56) for the overall competence shift, together with the elimination of low-competence students in the experimental group, underscores the practical significance of the intervention.

The motivational gains align with Dewey's (1910) principle of learning through direct experience and with recent evidence that outdoor and field-based instruction increases student engagement and interest (Mann et al., 2022; Entress, 2023). Working with a regionally relevant, ecologically significant species added a sense of place and purpose that is difficult to replicate in classroom-only settings, supporting the argument for integrating local biodiversity into curriculum design (Ramírez-Castañeda et al., 2022; Hu et al., 2025).

Cognitive improvements, as measured by the coefficient of knowledge completeness, are consistent with prior reports that inquiry-based tasks in plant anatomy and morphology deepen conceptual understanding (Koberstein-Schwarz et al., 2024; Irwanto et al., 2023). The hands-on experience with real microscopy samples allowed students to connect theoretical knowledge with observable structures, likely facilitating durable learning.

The most pronounced change occurred in the activity-based component, indicating that repeated exposure to scientific procedures — from field sampling to biometric analysis and data interpretation — fosters procedural fluency and independent research behavior. This finding mirrors earlier conclusions that sustained involvement in authentic research tasks is critical for developing research autonomy (Daryanes et al., 2025; Hujjatusnaini et al., 2022). Importantly, the absence of low-level students in the experimental group at post-test suggests a threshold effect: the intervention was sufficient to move all participants to at least a medium skill level.

From a curriculum-design perspective, the study demonstrates how Tyler's four fundamental dimensions — objectives, materials, methods, and assessment — can be coherently aligned within a field-based biology teacher-education unit. By explicitly stating research competence objectives, providing authentic disciplinary materials, employing an inquiry-based methodology, and applying a validated three-component assessment, the course became a closed-loop system that reinforced learning at each stage. This alignment may serve as a transferable model for other institutions aiming to strengthen practice-oriented curricula.

Regarding the biological findings, the diffuse-porous wood anatomy and the predominance of uni-seriate rays with large procumbent cells confirmed a moderate rooting potential. While the rooting results are not novel from a hardwood propagation standpoint, they served a crucial pedagogical function: students could compare predicted rooting capacity based on anatomical markers with actual experimental outcomes, thereby experiencing the nature of scientific inference. The integration of such biological data into a teacher education program remains rare and constitutes a methodological contribution that bridges disciplinary research and pedagogy.

Despite these positive outcomes, several limitations must be acknowledged. First, the sample was drawn from a single institution and a single academic year, limiting external validity. Multi-site replication and longitudinal follow-up are needed. Second, the quasi-experimental design with intact groups prevented full randomization; although pre-test equivalence was demonstrated, unmeasured variables could have influenced the results. Third, inter-rater reliability was reported only for the activity-based component; for the motivational and cognitive components, assessment relied on self-report and researcher-designed tests, for which full psychometric validation is pending. Fourth, chi-square assumptions were violated at the early measurement stages due to low frequencies in "high" cells; Fisher's exact test was used as a corrective measure, but this points to the need for larger samples. Fifth, the absence of assessor blinding for motivational and cognitive-component ratings introduces potential bias; future studies should employ blinded external examiners. Finally, the rooting experiments lacked rigorous inferential statistics in the original report; we retroactively performed ANOVA and Kruskal–Wallis tests, but future studies should include pre-registered analysis plans.

In conclusion, the study provides empirical evidence that a well-structured, field-based intervention using an endemic species can substantially improve research competencies among biology teacher candidates. The approach fosters motivation, deepens content knowledge, and moves students toward independent scientific inquiry. Replication with larger, more diverse samples and integration of digital tools are promising directions for further development.

CONCLUSION

This study demonstrated that the integration of anatomical and histological research on *Sorbus tianschanica* Rupr. into undergraduate biology education is an effective means of developing research competencies in future biology teachers. The proposed approach combines field sampling, laboratory microscopy, data analysis, and interpretation, thereby creating conditions for inquiry-based and practice-oriented learning.

Anatomical analysis revealed a diffuse-porous wood structure with predominance of uniseriate medullary rays. Rooting experiments confirmed that growth regulators significantly enhance rooting, with IAA and IBA showing the strongest effects. Pedagogically, the experimental group showed statistically significant improvements in motivation, cognitive understanding, and independent research activity, with no students remaining at the low competence level.

Statistical analysis ($\chi^2 = 16.16$; Cramér's $V = .56$) confirmed the effectiveness of the methodology. The findings support the inclusion of regionally significant plant species and rigorous research methods in undergraduate biology curricula to train competent, research-oriented biology teachers. The developed methodology can be recommended for use in higher education institutions and in conservation-oriented studies of endemic plant species of the Zhetysu Alatau.

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